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Doug Poland, Robert Simpson

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Introduction

It is desired to quantify the effect, in terms of radar cross-section (RCS), of the addition of a small aluminum reflector to the end of the V22 blades. This reflector was designed and manufactured in order to facilitate blade lag measurements by the 95 GHz Lawrence Livermore National Laboratory (LLNL) Radar Blade Tracker (RBT) system. The reflector used in these measurements was designed and fabricated at LLNL and is pictured in Figure 1.

Figure 1: LLNL tipcap reflector

Methodology

Radar cross-section (RCS) measurements were performed in an anechoic chamber in Building 141 at LLNL at various blade and antenna orientations and at frequencies ranging from 1-20 GHz. This chamber is rated at –100 dB over a range of 1-18 GHz. For each configuration, a dataset was taken with the standard aluminum endplate on the blade tip, and then the same measurement was repeated with the endplate replaced by the tipcap reflector.

Figure 2: The blade tip shown on the tilting/rotating stage in the B141 anechoic chamber at left, and a closeup of the tipcap reflector mounted on the blade tip.

The blade tip was set vertically upon a tilting and rotating stage which was controlled by a Newport MM3000 Motion Controller. An Apple PowerMac 8500 was used to control both the Newport and the HP 8510B Network Analyzer, coordinating stage motion and data acquisition. In order to minimize direct transmission from the transmit to the receive antenna, the transmit antenna was located closer to the target and radar absorbing material (RAM) was placed between the two. The bistatic angle was less than 10 degrees, hence the measured RCS is approximately equal to the monostatic RCS.
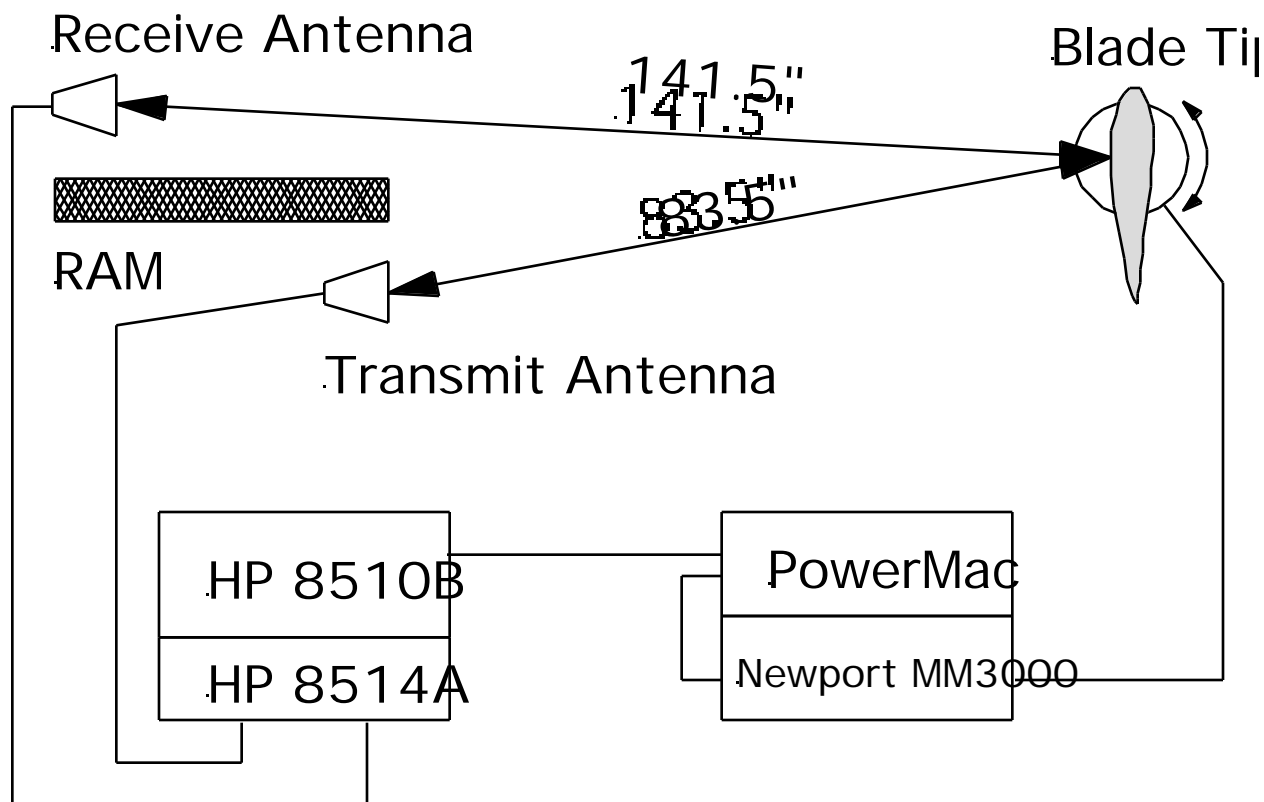

Figure 3: Schematic diagram of setup and equipment used for RCS measurements.

For each set of measurements, the calibration and measurement sequence was:

1) Set up the Network Analyzer:
    Desired frequency or range of frequencies
    1K averaging (take average of 1000 trials)
    401 points

2) Point the antennas toward each other and perform an indirect calibration

3) Rotate the antennas so they are directed toward the blade tip

4) Put the blade in place with the endplate installed on the tip; record S12 (P_r/P_t in dB)

5) Replace the endplate with the tipcap reflector and record S12

This sequence produced all of the data that was required for the RCS calculations.

The bistatic radar equation may be written

$$\frac{P_r}{P_t} = G_t \frac{1}{4\pi R_t^2} \sigma \frac{1}{4\pi R_r^2} \frac{G_r \lambda^2}{4\pi}$$

which represents the ratio of received to transmitted power when the signal is reflected off an object with RCS . If we point the antennas toward each other with separation R_c, there is no reflection and only one geometric loss term, giving

$$\frac{P_{r,c}}{P_t} = G_t \frac{1}{4\pi R_c^2} \frac{G_r \lambda^2}{4\pi}$$

We can use this calibration measurement to eliminate the antenna parameters from the RCS calculation:

$$\frac{P_r / P_t}{P_{r,c} / P_t} = \frac{R_c^2}{4\pi R_t^2 R_r^2} \sigma$$

where the ratio on the right-hand side is

$$\frac{R_c^2}{4\pi R_t^2 R_r^2} = \frac{(39 \quad 2.54)^2}{4\pi \, (83.5 \quad 2.54)^2 (141.5 \quad 2.54)^2} = 1.36 x 10^{-7} \, cm^{-2}$$

Then rearranging yields the expression for   in cm²:

$$\sigma = 7.35 x 10^6 \frac{P_r / P_t}{P_{r,c} / P_t}$$

Expressing all quantities in dB, then   in dB-cm² is

$$\sigma = 68.7 + (P_r / P_t) - (P_{r,c} / P_t)$$

Results

Presented in the following figures are the results of these measurements. Each plot shows blade tip RCS vs. angle as the blade tip is rotated through 360 degrees. In each plot, the noise floor of the instrument for the given frequency is shown in purple for comparison. The RCS of the blade tip with the standard end plate is shown in red, while the RCS of the blade tip with the tipcap reflector in place is shown in black. In most cases, the two measurements are indistinguishable. The uniform result is that the contribution of the tipcap reflector to the measured RCS of the blade tip is negligible. The various combinations of frequency, blade tip tilt and rotation, and antenna polarization did not reveal any configuration in which the effect of the tipcap reflector was distinguishable.

RCS vs. Frequency – Horizontal Polarization

The first set of measurements looked at the frequency dependence of the tipcap reflector RCS. This was done in two different ways. In the first measurement, the blade was positioned normal to the antennas with the polarization of the antennas aligned with the reflector (horizontal). With the blade stationary, the RCS measurement was performed over a range of 1-20 GHz. In the second RCS vs. Frequency measurement, various individual frequencies were used to examine the RCS as the blade was rotated.

RCS vs. Tilt Angle – Vertical Polarization

The effect of tilt was investigated as well. The frequency was set to 10 GHz and RCS measurements were performed through a 360 degree rotation with the blade tip set to various tilt angles. The antenna polarization was vertical for these measurements. The blade was tilted forward in two degree increments. It was found that the signal degraded fairly rapidly with increasing tilt and that again there was no discernible signature from the tipcap reflector.
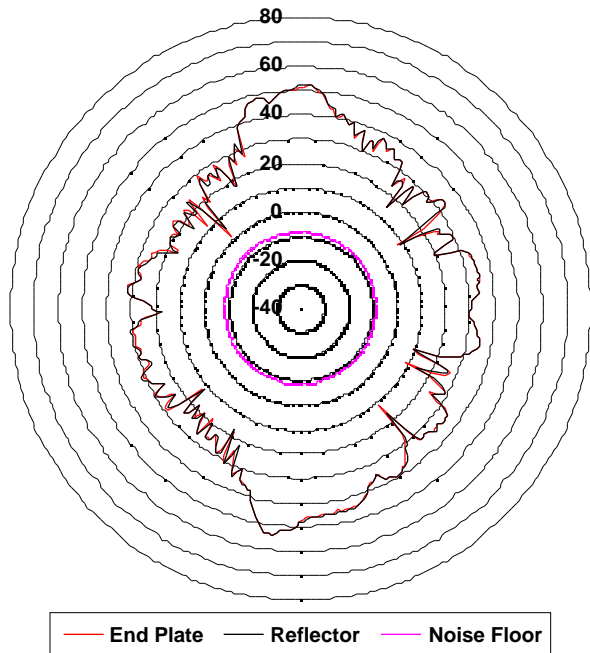
V22 Blade Tip RCS (dB-cm^2) - 1 GHz, 0° Tilt
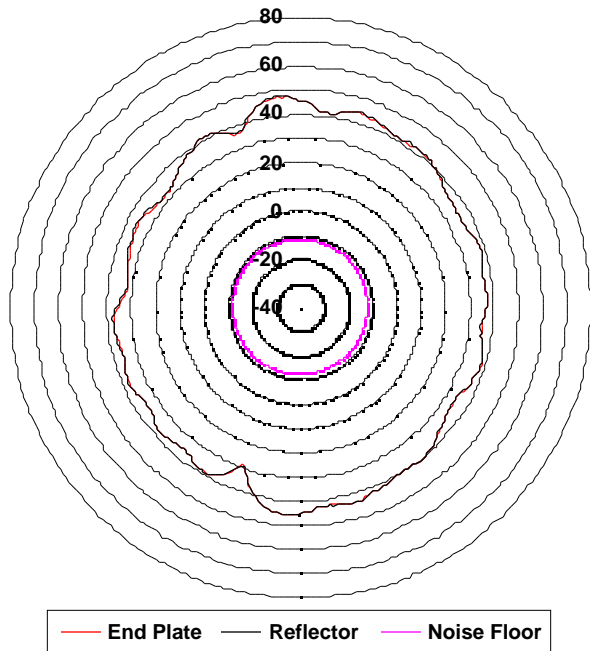
V22 Blade Tip RCS (dB-cm^2) - 2 GHz, 0° Tilt
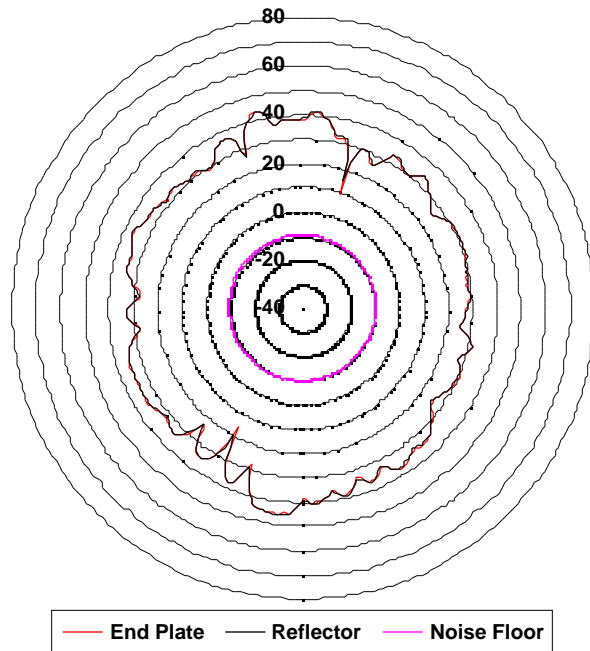
V22 Blade Tip RCS (dB-cm^2) - 5 GHz, 0° Tilt

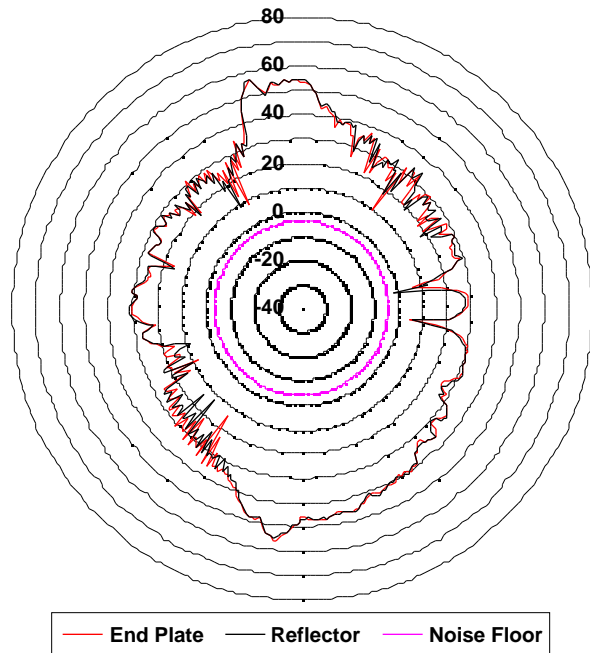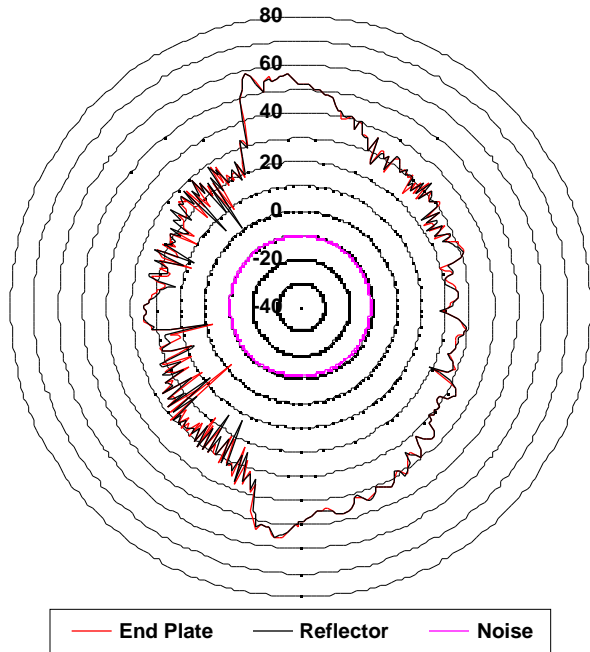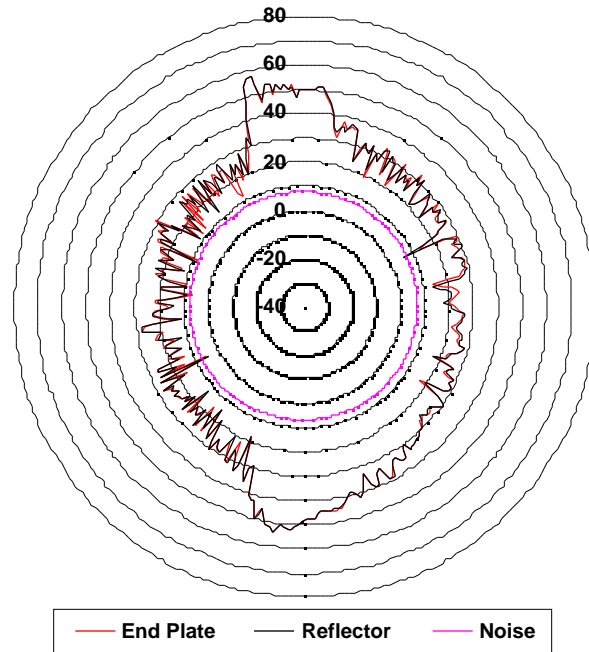**V22 Blade Tip RCS (dB-cm^2) - 10 GHz, 0° Tilt**

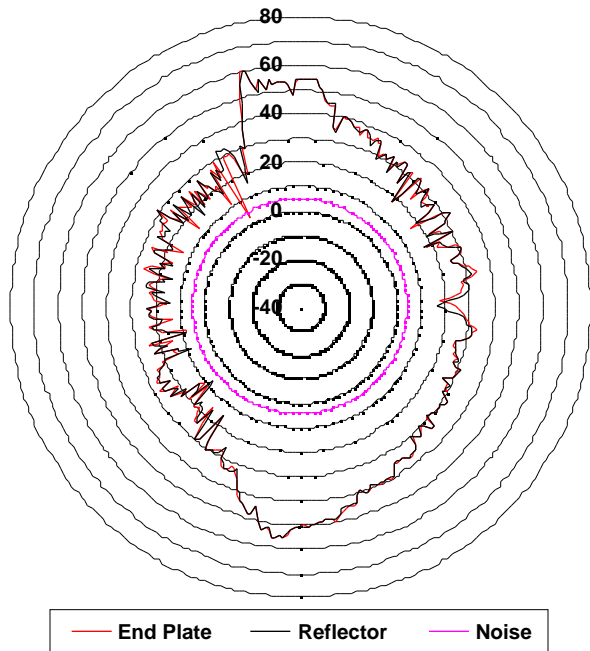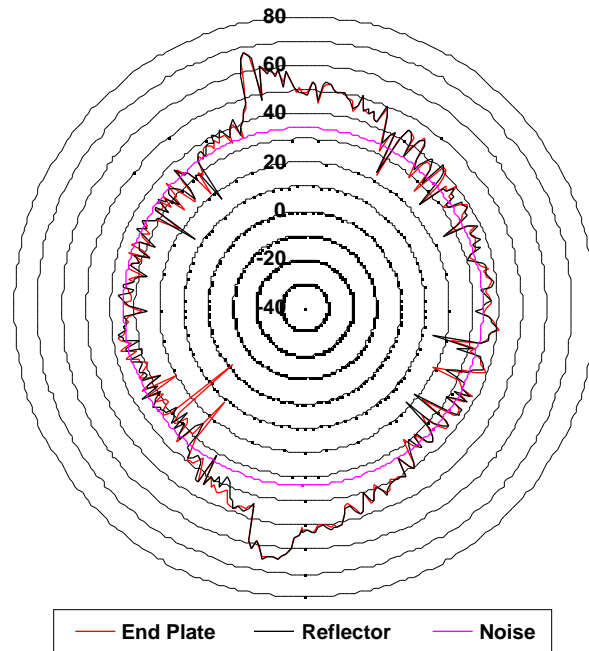**Figure 4:** RCS results for 1-10 GHz; horizontal antenna polarization.

V22 Blade Tip RCS (dB-cm^2) - 12 GHz, 0° Tilt

V22 Blade Tip RCS (dB-cm^2) - 15 GHz, 0° Tilt

V22 Blade Tip RCS (dB-cm^2) - 18 GHz, 0° Tilt

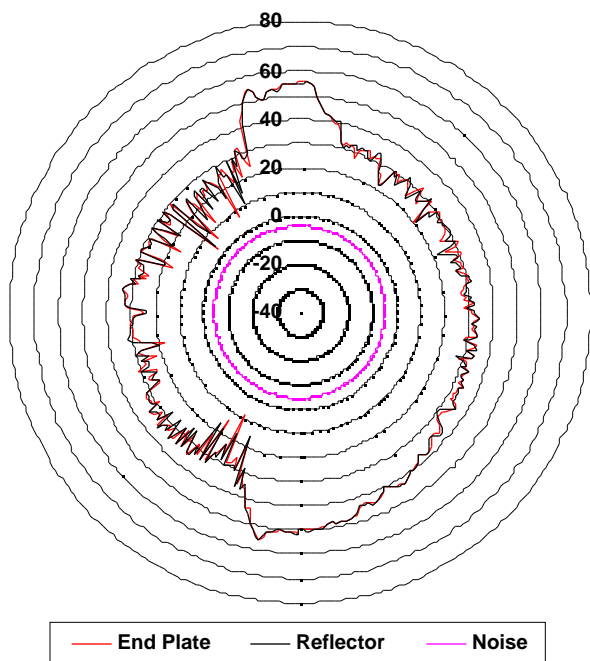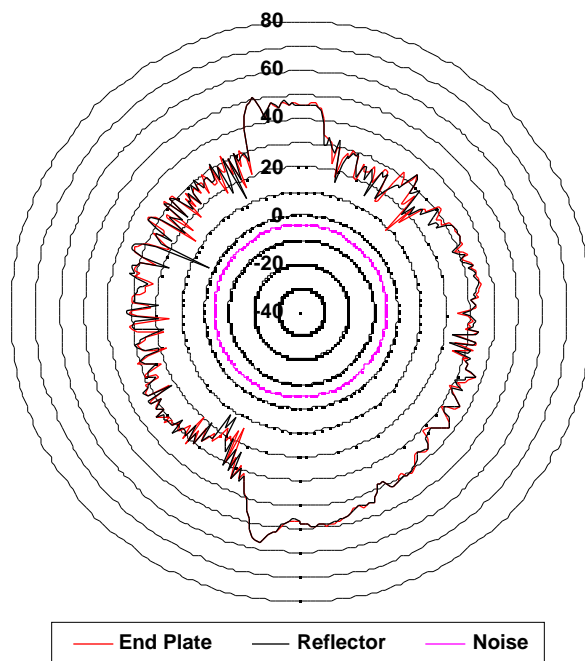**V22 Blade Tip RCS (dB-cm^2) - 20 GHz, 0° Tilt**

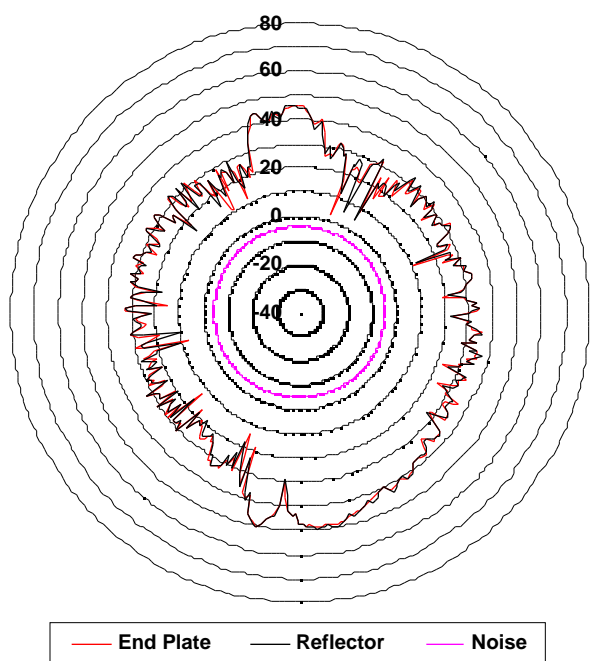**Figure 5:** RCS results for 12-20 GHz; horizontal antenna polarization.

V22 Blade Tip RCS (dB-cm^2) - 10 GHz, 0° Tilt
Vertical Antenna Polarization

V22 Blade Tip RCS (dB-cm^2) - 10 GHz, 2° Tilt
Vertical Antenna Polarization

V22 Blade Tip RCS (dB-cm^2) - 10 GHz, 4° Tilt
Vertical Antenna Polarization

V22 Blade Tip RCS (dB-cm^2) - 10 GHz, 6° Tilt
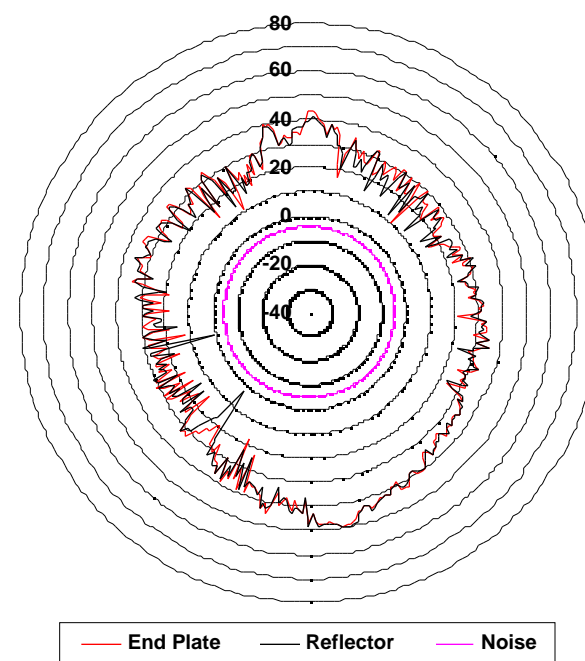**Vertical Antenna Polarization**

Figure 6: RCS results for various tilt angles at 10 GHz; vertical antenna polarization.